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SEASONAL GROWTH AND UPTAKE OF NUTRIENTS BY ORCHARDGRASS IRRIGAT--ETC(U)
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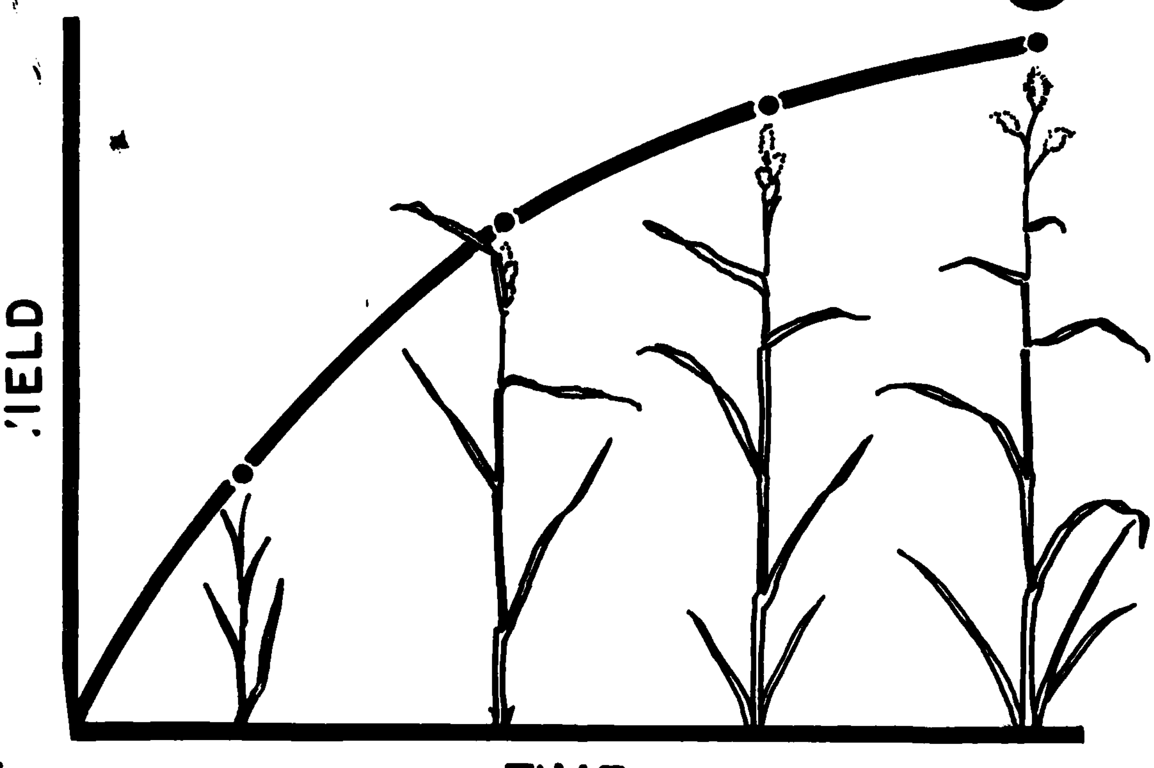

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For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide, *published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.*

Cover: *Growth stages of orchardgrass* (Dactylis glomerata *L.).*

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A 2-year field study determined the seasonal growth and nutrient accumulation of a forage grass receiving 7.5 cm/wk of primary treated domestic wastewater. The average N and P concentrations in the wastewater were 31.5 and 6.1 mg/L respectively. An established sward of Pennlate orchardgrass (*Dactylis glomerata* L.) was managed on an annual three cutting system. Grass samples were periodically taken to determine plant dry matter accumulation and uptake of N, P and K. Changes in nutrient uptake within a harvest period were related to both changes in dry matter accumulation and plant nutrient concentration. For maximum yields and nutrient removal, it is recommended that orchardgrass be initially harvested at the early heading stage of growth in the spring. Subsequent harvests should be performed at 5-to 6-week intervals. Average daily dry matter, N and P accumulation was greatest during the first harvest period

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20. Abstract (cont'd)

(May in Hanover, N.H.). This would be the most appropriate time to increase the application rate, thus treating excess wastewater stored during the winter. Estimates of monthly plant removal for N and P are presented as a guide in designing land treatment systems according to the procedures given in the EPA/Corps Land Treatment Design Manual.

PREFACE

This report was prepared by Antonio J. Palazzo, Research Agronomist, and John M. Graham, Biological Technician, of the Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. The study was conducted as a part of the U.S. Army Corps of Engineers Civil Works Research and Investigations Project under Work Unit CWIS 31633, *Optimization of Automated Procedures for Planning, Design and Management of Land Treatment of Wastewater.*

The authors would like to acknowledge T.F. Jenkins and J.R. Bouzoun of CRREL; C.E. Clapp, USDA-SEA; and J.R. Mitchel, University of New Hampshire for their technical review of this report. Appreciation is also expressed to C.F. Grant, University of New Hampshire, for assistance in the statistical design and analysis of the data; to H.L. McKim for his support as program manager; and to the CRREL Water Chemistry Laboratory. Special thanks to Eleanor Huke for drawing the cover illustration

SEASONAL GROWTH AND UPTAKE OF NUTRIENTS BY ORCHARDGRASS IRRIGATED WITH WASTEWATER

Antonio J. Palazzo and John M. Graham

INTRODUCTION

Land application is one method of wastewater treatment capable of meeting stringent water quality standards. The primary function of vegetation in land treatment systems is to remove certain wastewater constituents that conventional treatment cannot handle, especially N. Plant removal of N is necessary to prevent it from leaching through the soil profile. Hook and Burton (1979) recommended the harvesting of plant biomass as a reliable control of N leaching through soils irrigated with wastewater. Forage grasses are generally considered to be the most efficient N-removing crop. In a review of the nutrient uptake of crops in land treatment systems, Clapp et al (1978) reported that forage grasses can remove over 400 kg/ha of N annually as well as 29 to 56 kg/ha of P.

Identification of the forage grasses' peak nutrient uptake and growth times within a harvest period could lead to increased wastewater application rates because it would allow for more efficient plant utilization of wastewater constituents. Hook and Kardos (1976) reported on the yields of reed canarygrass which received secondary wastewater and was cut three times annually over a 10-year period. Their results showed that within a single season plant yields were greatest for the first cutting, followed by the second and then the third.

Clapp et al (1978) discussed the uptake of N by reed canarygrass during May and June. They noted that for grasses which received 6 cm/wk of wastewater, total N uptake increased up to mid-June and then leveled off; however, grasses which received 11 cm/wk of wastewater continued to accumulate N through June.

Martin et al. (1979) studied the effects of two, three and four time cutting schedules on grass yields under two municipal effluent application rates. At the high rate of application (10 cm/wk), reed canarygrass, orchardgrass and tall fescue were usually the best yielders with maximum persistence. Borrelli et al. (1978) and Martin et al. (1978) found no detrimental effects on the quality of forage grasses irrigated with sewage effluent.

Studies using commercial fertilizers as a nutrient source have shown that the removal of nutrients by forage grasses and their yields are highly dependent on cutting management. The greatest percentage of dry matter produced in a growing season is generally obtained during the first harvest or up to about mid-June (Duell 1960, Washko et al. 1967, Kunelius et al. 1974). Although yields of orchardgrass during this period have been shown to increase up to the flowering stage of growth (Gutenson 1963, Washko et al. 1967, Kunelius et al. 1974), greater annual yields have been reported when the initial harvest was at the early heading stage (Colby et al. 1965).

Orchardgrass has a good yield distribution throughout the season because of a high aftermath production following the first harvest (Kunelius et al. 1974, Jung and Baker 1975). Aftermath production is usually greater when the first cutting takes place at the early heading

stage and when additional N fertilizer is applied (Colby et al. 1965, Washko et al. 1967). Brown and Ashley (1974) reported that prompt tillering of plants will shorten the lag period after defoliation and increase aftermath production, while Auda et al. (1966) reported that N stimulated tillering and growth of orchardgrass. Pearce et al. (1965) found that the regrowth of orchardgrass was linear with time; both dry matter and leaf area accumulated faster in July than September.

The slowing of orchardgrass growth during subsequent harvests is physiological in nature and is not correlated with any phenotypic relationships as in the initial harvest when a seedhead is produced. Colby et al. (1965) and Jung and Baker (1975) affirmed that there was little advantage in separating harvests after the first cutting by more than 5 to 6 weeks. Jung and Baker (1975) and Taylor et al. (1968), who studied the regrowth of orchardgrass, stated that dry matter gains due to leaf development and losses due to leaf senescence were about equal after 30 to 35 days. Treharne et al. (1968) reported that orchardgrass maintained a high photosynthetic rate for 15 to 20 days and then declined. The chlorophyll content of the leaves dropped after 18 days and was negligible after 30 days when the leaves were fully senesced.

The objective of this research was to identify peak growth and nutrient accumulation periods of a forage grass irrigated with municipal wastewater. Orchardgrass was chosen because of its ability to respond to high N application rates. The identification of peak uptake periods during the growing season will be helpful in planning seasonal wastewater application rates to achieve a greater degree of renovation.

MATERIALS AND METHODS

A 2-year study was conducted during 1978 and 1979 at CRREL in Hanover, New Hampshire. The soil in the study area is a Hartland silt loam which overlies a well drained gravel soil. Prior to the application of wastewater, the soil was sampled to a 15-cm depth and analyzed and was found to contain 350 and 110 kg/ha of P and K, respectively, with a pH of 5.9.

The site was prepared and seeded in August 1977 with Pennlate orchardgrass (*Dactylis glomerata* L.). During preparation we applied 3 metric tons/ha of dolomite limestone, 50 kg/ha of N and 100 kg/ha of K. The experimental site is shown in Figure 1.

Domestic sewage provided by the town of Hanover was given primary treatment and applied by spray irrigation from 4 May to 15 October in 1978 and from 3 May to 5 September in 1979. There were 20 weekly applications in 1978 and 16 in 1979. Wastewater was applied at a rate of 7.5 cm/wk over the 2-year period, while each weekly application was administered over a 3-day period, 8 hr/day. The wastewater was also analyzed weekly to determine the amount of nutrients applied. It was found to be near neutral-

Figure 1. Test site.

ity in pH and to contain a mean of 31.5, 6.1 and 18.4 mg/L of total N, P and K respectively.

The forages were managed on a conventional three cut per year schedule. The rates of plant dry matter and nutrient accumulation were determined by periodically harvesting 1.3-m² sample plots during the growing season. The orchardgrass was cut with a sickle bar mower at a 7.5-cm height, collected and weighed to obtain the total fresh weight per plot.

An adjacent site with a similar soil type was used as a control in 1978. The site received 100 kg/ha of N from ammonium nitrate in May 1978, after which it was irrigated with fresh water at a rate of 7.5 cm/wk. Plant sampling techniques were similar to those used in 1978 in the wastewater-treated site and three 1.3-m² sample plots were harvested at each of the 12 sample dates.

Within the wastewater-treated area there were four 1.3-m² plots harvested at each of the 12 forage sampling dates in 1978 and three 1.3-m² plots harvested at 15 sampling dates in 1979. No plots were sampled more than once during each year of the study with the exception of those normally harvested during the three cutting schedules. Sample plots which were harvested on 7 June and 25 July in 1978 and 7 June and 26 July in 1979 were cut at subsequent times.

Vegetation samples from each sample plot or replication were dried at 70°C for 48 hr, after which the dry weight production was determined. In 1978, after drying and weighing, a composite tissue sample was prepared for analysis by taking two duplicate grab samples from the four sample plots harvested. The composite subsamples were ground and the duplicate samples analyzed. In retrospect, we should have analyzed a subsample from each sample plot so that relationships between yield and composition could have been independently examined. Therefore, in 1979 analyses were performed on samples from individual sample plots. The grab samples were analyzed for N, P and K according to Liegel and Schulte (1977).

RESULTS AND DISCUSSION

Nutrient application rates

As shown in Table 1, sufficient amounts of N and P were supplied by the 7.5-cm/wk wastewater application rate to avoid nutritional deficiencies of these elements. Greater amounts of N and P were applied during 1978 than in 1979. This higher loading rate was due to a longer application period and higher concentrations of N and P in the wastewater used during the third harvest period in 1978.

Dry matter accumulation and phenotypic relationships

There were no significant differences in total yields between 1978 and 1979; they totaled 10,870 and 11,080 kg/ha respectively. The yields obtained in this study were in agreement with others who have reported on the yields of forage grasses irrigated with wastewater (Clapp et al. 1978, Palazzo and McKim 1978, Martin et al. 1979).

As shown in Figure 2, dry matter accumulation for both years leveled off after 31 days of growth during the first harvest period. During the sec-

Table 1. Concentrations and total amounts of N and P applied to site during each harvest period.

Harvest period	Duration (weeks)	Wastewater concentration (mg/L) N	Wastewater concentration (mg/L) P	Total applied (kg/ha) N	Total applied (kg/ha) P
1978					
1	5	37.6	5.7	106	21
2	6	18.8	5.9	85	27
3	9	41.1	7.8	267	53
Total	20			458	101
1979					
1	5	34.7	7.0	130	26
2	4	30.2	5.9	128	26
3	6	26.6	4.2	122	20
Total	16			380	72

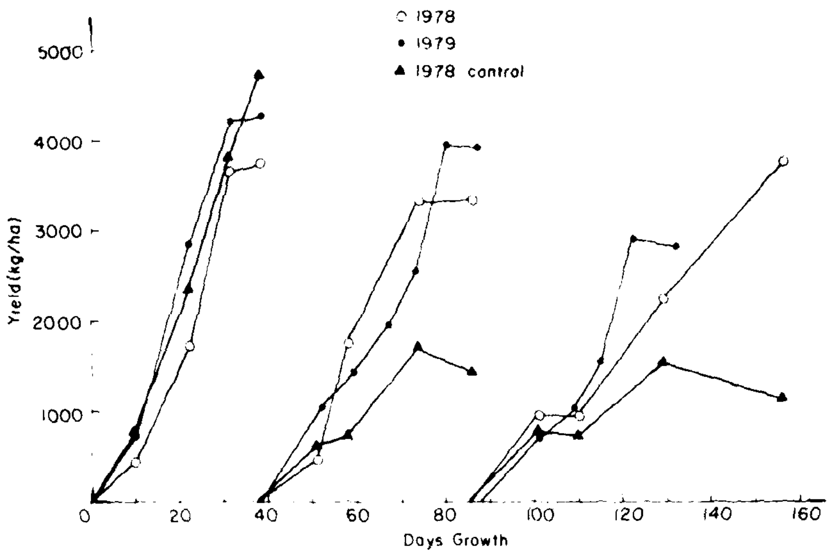

Figure 2. Seasonal dry matter accumulation.

Table 2 Plant yield and content of nutrients at various stages of growth during the first harvest period.

Plant stage	*1978 (kg ha)*	*1979 (kg ha)*
1. Leaf stage (10 May)		
Yield	442	742
Nitrogen	13	28
Phosphorous	2	4
Potassium	11	29
2. Head emergence (22 May)		
Yield	1719	2867
Nitrogen	44	80
Phosphorus	7	14
Potassium	77	132
3. Early heading (31 May)		
Yield	3693	4207
Nitrogen	109	117
Phosphorus	24	17
Potassium	179	149
4. Late heading (7 June)		
Yield	3743	4289
Nitrogen	3	129
Phosphorus	14	7
Potassium	150	182

1 2 3 4

ond harvest period of both years and the third period in 1979, dry matter accumulation ceased after 35 to 40 days. During the third period in 1978, accumulation slowed between 15 and 29 days and then increased for the remainder of the period. No differences were observed between yields during the last two sampling dates within each harvest period, with the exception of the third period in 1978.

Plants usually produced a seedhead during the first harvest period, while aftermath production was primarily leaf growth. The slowing of dry matter accumulation during the first harvest period occurred between 31 and 38 days of growth, which was between the early and late heading stages of plant development and just prior to flowering. At the end of the first harvest period, or after 38 days, the seedhead was fully

Table 3. Concentration (%) of N, P and K in plants during study.†

	1978				1979*		
Days Growth	*N*	*P*	*K*	*Days Growth*	*N*	*P*	*K*
First harvest period							
10	2.82	0.33	2.51	10	3.78a	0.47a	3.89a
22	2.56	0.40	4.49	22	2.77b	0.47a	4.63a
31	2.94	0.64	4.67	31	2.78b	0.41b	3.53a
38	1.96	0.37	4.02	38	2.99b	0.39b	4.23a
Second harvest period							
13	3.44	0.58	4.50	14	3.45a	0.39bc	3.51a
20	3.02	0.47	5.08	21	3.29a	0.40b	4.22a
36	2.37	0.41	3.93	29	3.40a	0.40b	3.31a
48	2.41	0.48	3.96	35	3.41a	0.37c	3.52a
				42	2.39b	0.44ab	3.32a
				49	2.50b	0.45a	3.17a
Third harvest period							
15	3.04	0.54	3.95	14	2.91a	0.42a	2.95b
29	2.39	0.60	4.70	21	3.46a	0.40a	3.73a
43	2.19	0.51	4.40	28	3.80a	0.38a	3.55a
70	2.66	0.50	3.39	35	3.07a	0.40a	3.55a

*Mean concentrations of individual nutrients within harvest periods followed by the same letter were not significantly different at the 5% level of probability according to the Duncan's Multiple Range Test (Little and Hills 1978).
†Nutrient analysis performed on oven-dried tissue.

open. The cessation of dry matter accumulation has been reported as being due to the senescence of plant leaves (Taylor et al. 1968, Treharne et al. 1968, Jung and Baker 1975, Page et al. 1977, Waldren and Flowerday 1979). The slowdown in growth found in this study occurred slightly earlier than the flowering stage reported in the literature (Autenson 1963, Washko et al. 1967, Kunelius et al. 1974). However, the 35 to 40 days of dry matter accumulation noted here during the second and third harvest periods was similar to that observed elsewhere (Colby et al. 1965, Jung and Baker 1975).

Nutrient uptake is initially very rapid during the first harvest period and then it levels off or declines when the plant begins to produce seed. In this study, plants were allowed to grow up to the late heading stage before the first harvest. At this time, nutrient accumulation leveled off in 1978 and was still increasing in 1979. The various stages of growth observed during this period and the nutrients removed at each one are shown in Table 2.

Other studies of orchardgrass have shown that maximum yields during the first harvest period occur at the flowering stage of growth (Autenson 1963, Washko et al. 1967, Kunelius et al. 1974), but maximum annual yields have been reported when the plants were initially harvested at early heading (Colby et al. 1965).

Nutrient concentrations

Table 3 shows the changes in the nutrient concentrations of plants during both growing seasons. In 1979, we statistically separated the mean N, P and K concentrations in the plants during each harvest period. Nitrogen concentrations were found to be greatest during the earlier portions of the first and second harvest periods and steady throughout the third. Phosphorus concentrations decreased during the first period and then increased during the second and were steady during the third. Potassium concentrations remained essentially unchanged throughout. The declines in plant nutrient concentrations during the first harvest period were similar to those reported by Wedin (1974) for smooth bromegrass.

Because of the sampling method we used for tissue analysis, we did not perform a similar statistical breakdown of the data in 1978. In general, N concentrations were lower and P and K higher in 1978 than in 1979. The only major decline in plant nutrient concentrations within the

Table 4. Mean concentrations of other macro- and micro-nutrients.

Harvest period	S (%)	Ca (%)	Mg (%)	Fe (ppm)	B (ppm)	Cu (ppm)	Zn (ppm)	Mn (ppm)	Cr (ppm)
1978									
First	0.32	0.50	0.22	503	5.52	11	34	91	1.36
Second	0.34	0.48	0.27	752	6.73	15	37	76	1.34
Third	0.33	0.53	0.28	523	6.35	21	40	73	1.63
1979									
First	0.24	0.39	0.22	1043	3.63	23	56	75	2.74
Second	0.31	0.50	0.26	417	5.16	16	39	50.8	2.12
Third	0.26	0.49	0.29	867	3.83	21	51	64	3.58
Control									
First	0.33	0.42	0.21	219	6.58	10	34	86	1.01
Second	0.32	0.49	0.23	203	0.59	13	37	76	1.07
Third	0.36	0.58	0.27	587	2.70	14	38	82	1.65

harvest periods occurred between 31 and 38 days of the first period in 1978. The reason for this decline is unknown. A Student's t-test disclosed statistical differences among the mean N concentrations.

Plant concentration of other elements

Nine other elements were also analyzed during this study (Table 4). The observed concentrations were within the range considered normal in plants with the exception of B, Cr, and Fe (Allaway 1968, Jones 1972, Marton and Matocha 1973, Melsted 1973, Reid and Jung 1974, Wedin 1974). Several of the values for Cr and Fe were above the tolerable levels of 2 and 750 ppm, respectively, reported by Melsted (1973). Boron levels were consistently below the levels considered normal in plants and ranged from 3.6 to 6.7 ppm. Allaway (1968), Jones (1972) and Melsted (1973) have shown the normal range of B in plants to be 7 to 75, 30 to 75, and 20 to 100 ppm respectively. Although B levels in the wastewater-irrigated plants were low they were greater than the levels found in the control plants.

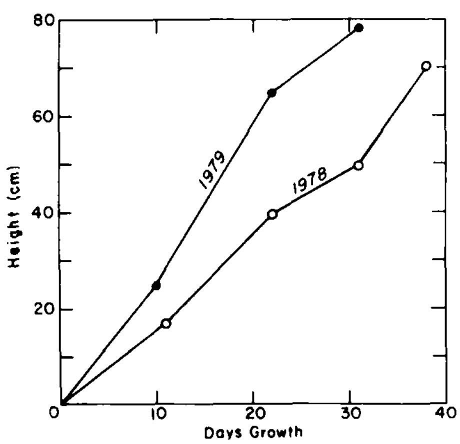

Figure 3. Plant heights during the first harvest period in 1978 and 1979.

Plant heights

The orchardgrass increased in height throughout the first harvest period of both seasons (Fig. 3). The greater plant heights in 1979 reflect the greater yields obtained that year. Plant heights were not considered to be a reliable indicator of nutrient uptake, especially during later sampling dates of the period. Plant heights continued to increase between 31 and 38 days growth in 1978 while nutrient uptake declined (Fig. 4). This problem could be related to the extension of the seedhead which would increase plant height during a period of slow nutrient uptake.

Percent plant dry weight

A measurement of the percent dry weight of the grasses was taken after drying tissue samples for 48 hr at each sample harvest date. In 1979 significant differences in percent dry weight were observed within the first and third harvest periods (Table 5). The greatest dry weight percentage was observed during the early portions of each period. Plant dry weight ranged from 17 to 31% throughout the year.

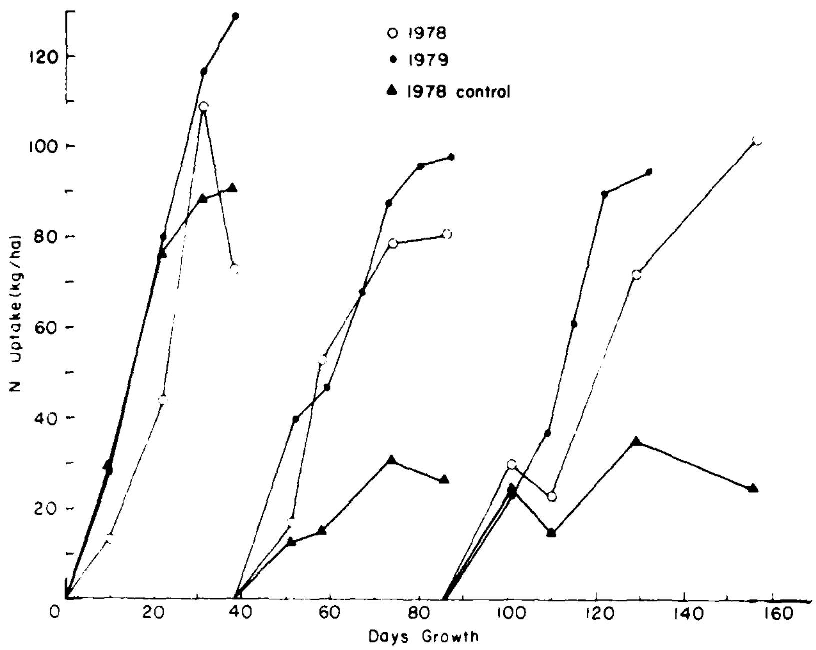

Figure 4. Seasonal plant N accumulation.

Table 5. Percent dry weight of plants at each cutting date in 1979.

First harvest		*Second harvest*		*Third harvest*	
Days growth	*Dry wt (%)*	*Days growth*	*Dry wt (%)*	*Days growth*	*Dry wt (%)*
10	24a*	14	22a	14	31a
22	22ab	21	16a	21	18b
31	14c	29	20a	28	18b
38	18bc	35	17a	35	18b
		42	19a	45	17b
		49	20a		

*Columns of numbers followed by the same letter were not significantly different at the 5% level of probability according to the Duncan's Multiple Range Test (Little and Hills 1978)

Nitrogen accumulation

The total annual plant uptake of N was 256 of 458 kg/ha applied during 1978 and 323 of 380 kg/ha applied during 1979. The final range in plant uptake of N among the main harvest periods was from 73 to 129 kg/ha during both years.

During the first harvest periods for both years and in the control in 1978, N uptake was essentially linear for the initial 31 days of plant growth (Fig. 4). In 1979, uptake continued to increase after this time, but in 1978 it declined dramatically. This rapid decline in 1978 was due to a decrease in the concentration of N in the plant after 31 days. After 38 days, plants grown in 1978 contained nearly 1% less N than in 1979 (Table 3).

A decline in the accumulation of N and other nutrients by plants during or after the flowering period has been noted in many annual plants. As previously mentioned, leaf senescence could be one factor in N loss. Herron et al. (1963) noted that sorghum plants lost N after the soft dough stage of growth. They attributed this loss to translocation of N and to respiration in excess of photosynthesis. Waldren and Flowerday (1979) noted that 80% of the N present in wheat at ma-

turity was taken up by anthesis. Singh and Modgal (1979) reported that 85-90% of the N contained in rice was absorbed prior to heading.

During the second harvest period N accumulation increased up to 35 to 40 days and then leveled off. The slowing of N accumulation was due to a decline in plant nutrient concentration and a leveling off in dry matter accumulation. In 1979, during the third harvest period, N accumulation increased up to 35 days and then leveled off because of a slowing in dry matter accumulation. In 1978 plant N accumulation decreased after 15 days, increased again after 29 days and continued to increase until the end of the period. A leveling off in dry matter accumulation and a drop in plant nutrient concentration during this time was responsible for the leveling off in N accumulation. Because of the lower quantity of N applied, uptake of N by the control plants during the second and third harvest periods was lower then that of the plants treated with wastewater (Table A4).

The plants accumulated a total of 56 and 85% of the applied N during 1978 and 1979 respectively. The lower percentage removed in 1978 was related to the drop in N uptake during the first harvest period and the greater annual rate of application.

Phosphorus accumulation

Total annual plant accumulation of P was 48.7 of 101 kg/ha applied in 1978 and 46.4 of 72 kg/ha applied in 1979, about 16% of that for N. Plant uptake accounted for 49 and 64% of the applied P in 1978 and 1979 respectively. These uptake values were in agreement with those presented by Sopper and Kardos (1974), Clapp et al. (1978), and Palazzo and McKim (1978). Total plant accumulation of P increased slightly at each harvest period in 1978, and in 1979 it was steady during the first and second periods while dropping slightly during the third. Sopper and Kardos (1974) found uptake patterns for P similar to those observed here in 1979.

Phosphorus accumulation during both seasons initially increased and then leveled off after 31 days in the first harvest period and 40 days in the second period (Fig. 5). The reason for the decline in P accumulation at the end of the first harvest period in 1978 was similar to that for N: a decrease in P concentration by the plants. Phosphorus concentrations declined from 0.64 to 0.37%, while dry matter remained constant. The slowing in P accumulation during the third harvest period in 1978 was primarily due to a leveling off in dry matter accumulation. In 1979, P accumulation during the third period slowed after 35 days. Since no P was applied to the control plants, plant uptake was lower than that of the treated plants (Table A4).

Potassium accumulation

The plants accumulated K rapidly during the first harvest period (Fig. 6). This was apparently related to luxury consumption of the K which was applied by fertilization in May. Accumulation leveled off after 31 days in 1978 but continued to increase in 1979. Potassium accumulation during most of the second harvest period leveled off 35 to 40 days after cutting, but K accumulation was similar to that of N and P during the third harvest period. In general, the rate of K accumulation was most affected by the rate of dry matter accumulation.

Average daily accumulation

As shown in Table 6, the most intense period of average daily dry matter, N and P accumulation occurred during the first harvest period. This is the shortest period, with a majority of the accumulation occurring during the month of May. The rate of average daily dry matter accumulation during the second and third harvest periods was about 70 and 55% of that of the first period respectively. During 1979 the rate of daily dry matter, N and P accumulation was greater than in 1978. The annual decline in daily accumulation of N between harvest periods in 1978 would have been greater if the N concentrations at the end of the first harvest period had not been so low (1.96%).

The results show that higher wastewater application rates could be used during the first harvest period. This was mostly during the month of May in Hanover, New Hampshire. Fortunately, this period occurs immediately after the winter when wastewater is usually stored. Therefore, the spring would be an appropriate time to increase the application rate.

Monthly uptake estimates

In the design of land treatment systems, nutrient and water balance sheets are usually developed on a monthly basis (EPA 1977). Monthly uptake values are difficult to find since forage crops are not usually harvested this frequently. If they were, significant reductions could occur in persistence, yield and nutrient uptake.

Monthly estimates of nutrient uptake were generated from the data recorded in this study

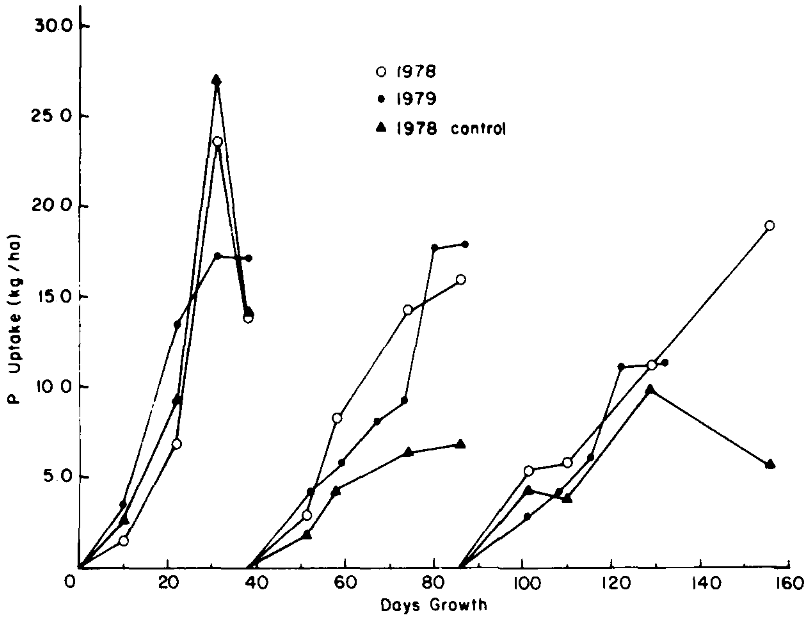

Figure 5. Seasonal plant P accumulation.

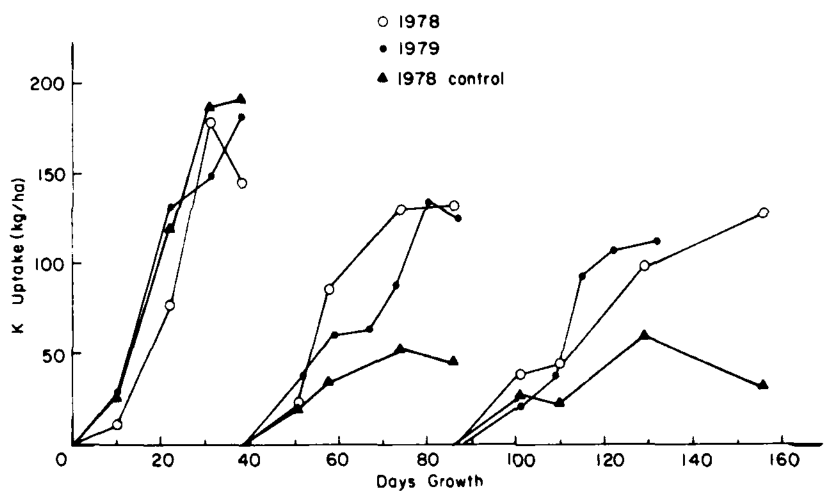

Figure 6. Seasonal plant K accumulation.

Table 6. Average daily dry matter, N and P accumulation during each harvest period (kg/ha).

Year and period	Days growth	Average daily accumulation: Dry matter	N	P
1978				
1	38	99	1.9	0.37
2	48	69	1.7	0.33
3	70	54	1.5	0.27
1979				
1	38	113	3.4	0.45
2	49	81	2.0	0.37
3	45	63	2.1	0.24

Table 7. Estimates of monthly plant uptake of nutrients (kg/ha).

	Month					
Element	*May*	*June*	*July*	*Aug*	*Sept*	*Total*
N	105	68	41	60	26	300
P	18	9	8	9	4	48

(Table 7). It should be noted here that these are only estimates and not actual uptake values. These estimates assume that the last cutting occurs in mid-September. Plant uptake will continue after this time but it was not recorded since plants are not normally harvested after this time in New Hampshire.

SUMMARY AND CONCLUSIONS

For maximum yields and the greatest removal of nutrients, orchardgrass should be initially harvested at the early heading stage of growth. After the first harvest, the forage should be cut at 5- to 6-week intervals when growth will consist primarily of leaves with only a few seedheads.

Plants accumulated dry matter and P up to 31 days during the initial harvest period, which occurred between the early and late heading stages of growth. Plant accumulation of N and K also leveled off after 31 days in 1978 but continued to increase until the end of the period in 1979. Nutrients and dry matter accumulated up to 35 to 40 days during the second harvest period. During the third harvest period in 1979, plant growth was similar to that of the second growing period, while in 1978 accumulation slowed after 15 days but increased again after 29 days. Change in nutrient uptake within a harvest period was related to both changes in dry matter accumulation and plant nutrient concentration.

The orchardgrass was found to accumulate the greatest average daily amounts of N and P during the initial harvest period. Therefore, this would be the most appropriate time to increase the wastewater application rate, thus using the excess wastewater stored during the winter season.

Plant accumulation of nutrients was more rapid earlier in a harvest period. Therefore, instead of set weekly application rates, it may be more advantageous to apply greater amounts of wastewater earlier in a harvest period. Rates can then be reduced with time until the period ends.

From the data gathered here, estimates of the monthly plant uptake of N and P were determined. This information could be useful in the design of land treatment systems.

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APPENDIX A: EXPERIMENTAL DATA

Table A1. Plant yields and uptake of N, P and K at each sampling time during the study. (Averages of following data.)

1978 Days growth	Yield	N	P	K	1979 Days growth	Yield	N	P	K
	(kg/ha)					(kg/ha)			
First harvest period									
10	442	13	2	11	10	742	28	4	29
22	1719	44	7	77	22	2867	80	14	132
31	3693	109	24	179	31	4207	117	17	149
38	3743	73	14	150	38	4289	129	17	182
Second harvest period									
13	493	17	3	22	14	1070	40	4	38
20	1736	53	8	86	21	1443	47	6	61
36	3318	79	14	130	29	1989	68	8	64
48	3335	81	16	132	35	2559	88	9	88
					42	3972	96	18	134
					49	3948	98	18	126
Third harvest period									
15	987	30	5	39	14	714	23	3	21
29	953	23	6	45	21	1056	37	4	38
43	2263	72	11	99	28	1589	61	6	94
70	3794	102	19	128	35	2930	90	11	103
					45	2843	95	11	113

Table A2. Plant yields (kg/ha), composition (mg/L) and uptake (kg/ha) of N, P and K by orchardgrass irrigated with wastewater in 1978.

Harvest period	Cutting date	Replications A	B	C	D	Mean
Plant yields						
1	10 May	272	408	681	408	442
1	22 May	1497	1225	1906	2246	1719
1	31 May	2859	3403	5445	3063	3693
1	7 June	2450	4764	3471	4288	3743
2	20 June	476	544	613	340	493
2	27 June	1974	2314	1361	1293	1736
2	13 July	2994	3811	2858	3607	3318
2	25 July	3675	2178	4083	3403	3335
3	9 August	749	1429	953	817	987
3	23 August	817	1157	749	1089	953
3	6 September	1906	2042	2518	2586	2263
3	3 October	3267	2722	4219	4968	3794
Plant N concentrations						
1	10 May	3.04	2.62	-	-	2.82
1	22 May	2.16	2.97	-	-	2.56
1	31 May	2.90	2.98	-	-	2.94
1	7 June	1.92	2.00	-	-	1.96
2	20 June	3.66	3.23	-	-	3.44
2	27 June	3.41	2.64	-	-	3.02
2	13 July	2.38	2.36	-	-	2.37
2	25 July	2.24	2.59	-	-	2.41

Table A2. (cont'd).

Harvest period	Cutting date	Replications A	B	C	D	Mean
3	9 August	3.68	2.40	-	-	3.04
3	23 August	2.76	2.03	-	-	2.39
3	6 September	3.12	3.27	-	-	3.20
3	3 October	2.66	2.67	-	-	2.66
Plant N uptake						
1	10 May	8	12	19	12	13
1	22 May	38	31	49	58	44
1	31 May	84	100	160	90	109
1	7 June	48	93	68	84	73
2	20 June	16	19	21	12	17
2	27 June	60	70	41	39	53
2	13 July	71	90	68	85	79
2	25 July	89	53	99	82	81
3	9 August	23	43	29	25	30
3	23 August	20	28	18	26	23
3	6 September	61	65	80	83	72
3	3 October	88	73	113	133	102
Plant P concentrations						
1	10 May	0.35	0.34	-	-	0.35
1	22 May	0.35	0.45	-	-	0.40
1	31 May	0.66	0.62	-	-	0.64
1	7 June	0.34	0.40	-	-	0.37
2	20 June	0.59	0.58	-	-	0.58
2	27 June	0.48	0.47	-	-	0.47
2	13 July	0.44	0.41	-	-	0.42
2	25 July	0.48	0.48	-	-	0.48
3	9 August	0.62	0.47	-	-	0.54
3	23 August	0.68	0.53	-	-	0.60
3	6 September	0.53	0.49	-	-	0.51
3	3 October	0.47	0.53	-	-	0.50
Plant P uptake						
1	10 May	0.9	1.4	2.3	1.4	1.5
1	22 May	6.0	4.9	7.6	9.0	6.9
1	31 May	18.3	21.8	34.8	19.6	28.6
1	7 June	9.1	17.6	12.8	15.9	13.8
2	20 June	2.8	3.2	3.6	2.0	2.9
2	27 June	9.5	11.1	6.5	6.2	8.3
2	13 July	12.9	16.4	12.3	15.5	14.3
2	25 July	17.6	10.5	19.6	16.3	16.0
3	9 August	4.1	7.8	5.2	4.5	5.4
3	23 August	4.9	7.0	4.5	6.6	5.8
3	6 September	9.7	10.4	12.8	13.2	11.3
3	3 October	16.3	13.6	21.1	24.8	18.9
Plant K concentrations						
1	10 May	2.92	2.11	-	-	2.52
1	22 May	4.04	4.94	-	-	4.49
1	31 May	4.91	4.83	-	-	4.67
1	7 June	3.96	4.08	-	-	4.02
2	20 June	4.61	4.40	-	-	4.50
2	27 June	4.74	5.42	-	-	5.08
2	13 July	3.96	3.91	-	-	3.93
2	25 July	3.81	4.12	-	-	3.96
3	9 August	4.31	3.59	-	-	3.95
3	23 August	4.87	4.54	-	-	4.70
3	6 September	4.28	4.52	-	-	4.40
3	3 October	3.89	2.89	-	-	3.39

Table A2. (cont'd).

Harvest period	Cutting date	Replications A	B	C	D	Mean
Plant K uptake						
1	10 May	7	10	17	10	11
1	22 May	67	55	86	101	77
1	31 May	139	166	265	149	179
1	7 June	98	192	140	172	150
2	20 June	21	25	28	15	22
2	27 June	100	118	69	66	86
2	13 July	118	150	113	142	130
2	25 July	146	86	162	135	132
3	9 August	30	56	38	32	39
3	23 August	38	54	35	51	45
3	6 September	84	90	111	114	99
3	3 October	111	92	143	168	128

Table A3. Plant yields (kg/ha), composition (mg/L) and uptake (kg/ha) of N, P and K by orchardgrass irrigated with wastewater in 1979.

Harvest period	Cutting date	Replications A	B	C	Mean
Plant yields					
1	10 May	596	464	1167	742
1	22 May	3545	2626	2431	2867
1	31 May	2781	5407	4434	4207
1	7 June	4218	4982	3668	4289
2	21 June	828	1265	1117	1070
2	28 June	1277	1875	1177	1443
2	6 July	1670	1563	2735	1989
2	12 July	1934	3692	2051	2559
2	19 July	2735	4083	5099	3972
2	26 July	3583	4044	4218	3948
3	9 August	481	934	726	714
3	16 August	1143	811	1213	1056
3	23 August	1498	1568	1701	1589
3	30 August	1758	3341	3692	2930
3	10 September	2159	2501	3868	2843
Plant N concentration					
1	10 May	3.78	3.82	3.73	3.78
1	22 May	2.99	2.82	2.50	2.77
1	31 May	2.72	2.78	2.84	2.78
1	7 June	2.91	3.27	2.78	2.99
2	21 June	3.55	3.83	2.98	3.45
2	28 June	3.26	3.03	3.58	3.29
2	6 July	3.38	3.22	3.60	3.40
2	12 July	3.20	3.50	3.52	3.41
2	19 July	2.12	2.81	2.23	2.39
2	26 July	2.67	2.52	2.31	2.50
3	9 August	2.42	3.34	2.98	2.91
3	16 August	3.40	3.26	3.72	3.46
3	23 August	3.71	3.57	4.11	3.80
3	30 August	3.05	3.25	2.92	3.07
3	10 September	3.30	3.68	3.12	3.37
Plant N uptake					
1	10 May	23	18	44	28
1	22 May	106	74	61	80
1	31 May	76	150	126	117
1	7 June	123	163	102	129
2	21 June	29	48	43	40
2	28 June	42	57	42	47
2	6 July	36	50	98	68
2	12 July	62	129	72	88

Table A3. (cont'd).

Harvest period	Cutting date	Replications A	B	C	Mean
2	19 July	58	115	114	96
2	26 July	97	101	97	98
3	9 August	12	31	27	23
3	16 August	39	26	45	37
3	23 August	56	56	70	61
3	30 August	54	109	108	90
3	10 September	71	92	121	95
Plant P concentrations					
1	10 May	0.47	0.48	0.47	0.47
1	22 May	0.46	0.50	0.46	0.47
1	31 May	0.40	0.41	0.41	0.41
1	7 June	0.38	0.45	0.35	0.39
2	21 June	0.38	0.41	0.37	0.39
2	28 June	0.43	0.40	0.38	0.40
2	6 July	0.38	0.41	0.42	0.40
2	12 July	0.37	0.33	0.41	0.37
2	19 July	0.42	0.48	0.43	0.44
2	26 July	0.45	0.47	0.44	0.45
3	9 August	0.48	0.32	0.45	0.42
3	16 August	0.38	0.44	0.38	0.40
3	23 August	0.38	0.37	0.40	0.38
3	30 August	0.48	0.37	0.35	0.40
3	10 September	0.41	0.42	0.38	0.40
Plant P uptake					
1	10 May	2.8	2.2	5.4	3.5
	22 May	16.3	13.1	11.2	13.5
	31 May	11.1	22.2	18.2	17.2
1	7 June	16.0	22.4	12.8	17.1
2	21 June	3.5	5.2	4.1	4.2
2	28 June	5.5	7.5	4.5	5.8
2	6 July	6.3	6.4	11.5	8.1
2	12 July	7.2	12.2	8.4	9.3
2	19 July	11.5	19.6	21.9	17.7
2	26 July	16.1	19.0	18.6	17.9
3	9 August	2.3	3.0	2.8	2.7
3	16 August	4.3	3.6	4.6	4.2
3	23 August	5.7	5.8	6.8	6.1
3	30 August	8.4	12.4	12.9	11.2
3	10 September	8.9	10.5	14.7	11.4
Plant K concentrations					
1	10 May	4.37	3.55	3.75	3.89
1	22 May	4.40	5.00	4.50	4.63
1	31 May	3.58	3.66	3.35	3.53
1	7 June	3.90	4.49	4.29	4.23
2	21 June	3.42	3.97	3.14	3.51
2	28 June	3.75	4.55	4.37	4.22
2	6 July	3.68	3.23	3.01	3.31
2	12 July	3.20	3.16	4.21	3.52
2	19 July	3.12	3.14	3.69	3.32
2	26 July	2.75	3.29	3.46	3.17
3	9 August	2.50	3.04	3.30	2.95
3	16 August	3.75	3.60	3.84	3.73
3	23 August	3.32	3.66	3.68	3.55
3	30 August	3.79	3.59	3.27	3.55
3	10 September	3.69	4.36	3.86	3.97
Plant K uptake					
1	10 May	26	16	44	29
1	22 May	156	131	109	132
1	31 May	100	198	149	149
1	7 June	164	224	157	182
2	21 June	28	50	35	38
2	28 June	48	85	51	61

Table A3. (cont'd).

Harvest period	Cutting date	Replications A	B	C	Mean
2	6 July	61	50	82	64
2	12 July	62	117	86	88
2	19 July	85	128	188	134
2	26 July	99	133	146	126
3	9 August	12	28	24	21
3	16 August	42	29	44	38
3	23 August	52	120	110	94
3	30 August	67	120	121	103
3	10 September	80	109	149	113
Percent plant dry weight					
1	10 May	0.23	0.25	0.25	0.24
1	22 May	0.27	0.17	0.21	0.22
1	31 May	0.15	0.14	0.14	0.14
1	7 June	0.21	0.15	0.18	0.18
2	21 June	0.25	0.20	0.22	0.22
2	28 June	0.17	0.16	0.16	0.16
2	6 July	0.19	0.20	0.20	0.20
2	12 July	0.18	0.18	0.15	0.17
2	19 July	0.20	0.19	0.18	0.19
2	26 July	0.23	0.17	0.19	0.20
3	9 August	0.37	0.27	0.29	0.31
3	16 August	0.18	0.19	0.18	0.18
3	23 August	0.19	0.17	0.17	0.18
3	30 August	0.18	0.19	0.18	0.18
3	10 September	0.17	0.16	0.18	0.17

Table A4. Plant yields (kg/ha), composition (mg/L) and uptake (kg/ha) of N, P and K by orchardgrass control plants in 1973.

Harvest period	Cutting date	Replications A	B	C	Mean
Plant yields					
1	10 May	816	680	884	793
1	22 May	1496	2244	3332	2357
1	31 May	2516	5508	3468	3831
1	7 June	5032	3808	5440	4760
2	20 June	544	680	612	612
2	27 June	408	1088	680	725
2	13 July	1632	1428	2040	1700
2	25 July	1224	1564	1496	1428
3	9 August	408	952	1020	793
3	23 August	680	544	952	725
3	6 September	1428	1496	1768	1564
3	3 October	748	1496	1156	1133
Plant N concentration					
1	10 May	3.76	3.81	-	3.79
1	22 May	2.79	3.72	-	3.25
1	31 May	2.34	2.34	-	2.34
1	7 June	1.77	2.10	-	1.93
2	20 June	2.00	2.32	-	2.16
2	27 June	2.07	2.28	-	2.17
2	13 July	1.74	1.96	-	1.85
2	25 July	2.08	1.64	-	1.86
3	9 August	3.30	2.97	-	3.13
3	23 August	2.00	2.16	-	2.08
3	6 September	2.08	2.52	-	2.30
3	3 October	2.68	1.80	-	2.24

Table A4. (cont'd).

Harvest period	Cutting date	Replications A	Replications B	Replications C	Mean
Plant N uptake					
1	10 May	30.68	25.57	33.24	29.83
1	22 May	48.62	72.93	108.29	76.61
1	31 May	58.87	128.89	81.15	89.64
1	7 June	97.11	73.49	104.99	91.86
2	20 June	11.75	14.69	13.21	13.21
2	27 June	8.85	23.60	14.75	15.73
2	13 July	30.19	26.41	37.74	31.44
2	25 July	22.76	29.09	27.82	26.55
3	9 August	12.77	29.79	31.92	24.82
3	23 August	14.14	11.31	19.80	15.08
3	6 September	32.84	34.40	40.66	35.96
3	3 October	16.75	33.51	25.89	25.33
Plant P concentrations					
1	10 May	0.36	0.33	-	0.34
1	22 May	0.41	0.40	-	0.40
1	31 May	0.73	0.70	-	0.71
1	7 June	0.36	0.25	-	0.30
2	20 June	0.31	0.32	-	0.31
2	27 June	0.57	0.61	-	0.59
2	13 July	0.42	0.34	-	0.38
2	25 July	0.45	0.51	-	0.48
3	9 August	0.51	0.62	-	0.56
3	23 August	0.52	0.57	-	0.54
3	6 September	0.73	0.55	-	0.64
	3 October	0.53	0.50	-	0.51
Plant P uptake					
1	10 May	2.8	2.3	3.0	2.7
1	22 May	6.0	9.0	13.3	9.4
1	31 May	17.6	39.1	24.6	27.1
1	7 June	15.1	11.4	16.3	14.3
2	20 June	1.7	2.1	1.9	1.9
2	27 June	2.4	6.4	4.0	4.3
2	13 July	6.2	5.4	7.8	6.4
2	25 July	5.9	7.5	7.2	6.9
3	9 August	2.3	5.3	5.7	4.4
3	23 August	3.7	2.9	5.1	3.9
3	6 September	9.1	9.6	11.3	10.0
3	3 October	3.8	7.6	5.9	5.8
Plant K concentrations					
1	10 May	3.51	3.69	-	3.60
1	22 May	4.44	5.84	-	5.14
1	31 May	4.93	5.04	-	4.96
1	7 June	4.22	3.90	-	4.06
2	20 June	3.16	3.41	-	3.28
2	27 June	4.87	4.88	-	4.87
2	13 July	2.73	3.66	-	3.19
2	25 July	3.48	3.09	-	3.28
3	9 August	2.65	4.34	-	3.49
3	23 August	2.95	3.79	-	3.37
3	6 September	3.59	4.16	-	3.87
3	3 October	2.89	3.15	-	3.02
Plant K uptake					
1	10 May	29	24	32	29
1	22 May	77	115	171	121
1	31 May	125	273	172	190
1	7 June	204	155	221	193
2	20 June	18	22	20	20
2	27 June	20	53	33	35
2	13 July	52	46	65	54
2	25 July	40	50	49	46

Table A4. (cont'd).

Harvest period	Cutting date	Replications A	B	C	Mean
3	9 August	14	33	36	28
3	23 August	23	18	32	24
3	6 September	55	58	68	61
3	3 October	23	45	35	34

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